Submission 12

An estimation of Snake River drawdown survival

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This paper outlines an approach to evaluate the impacts of drawdown on the mortality of spring and summer chinook survival. It uses mathematical analysis, crisp survival results and information from the Lower Granite Reservoir drawdown study in 1992 to estimate possible ranges of survival under varying predator behavior assumptions.

From a mechanistic perspective, drawdown will alter the environment in several ways that can be counteracting. Drawdown increases the velocity of the water and so it decreases the travel time of fish through the Snake River. This decreases the exposure to predators and contributes to increasing survival over the full pool survival. A counter impact occurs because as the reservoirs are drawn down the predators are compresses into a smaller area which increases the effective density of predators and contributes to a decreasing survival. On the other hand the increased velocity increases sediment transport which increases water turbidity and decreases the visual foraging area of the predators. This contributes to increasing survival. These factors are all interactive so it is not intuitively clear how the drawdown will effect survival. The following model has empirical and mechanistic elements that formally expresses the interactions of these factors.

To begin we imply a survival equation that allows for both distance dependent and time dependent components of survival. The details of this model are presented in (Anderson et al 1998). The model is based on an analogy to the mean free path of molecules and partitions migration behavior into directed and diffusive components of fish migration. When the migration is fully directed, so fish experience little diffusive movement the mortality is a function of distance only and is independent of the amount of time in the river system. Spring chinook, which have a rapid migration, have a directed like migration behavior. When fish are moving slower than the water velocity they have more random movements and their migration is more diffusive like. Subyearling or fall chinook have a more diffusive like behavior. The distinction between the two behaviors can be characterized by the ratio of the square of the diffusive velocity to the square of the directed or average migration velocity of the fish. The survival of fish S is defined

$$S = \exp(-\alpha P(X^{2} + w^{2} T^{2})^{1/2}) \qquad (1)$$

where X is the distance traveled T is the travel time, w is the speed of the random or diffusive element of the migration, a is the effective search area of a predator, and P is the predator density per unit volume.

To develop how this equation changes with drawdown the coefficients a, P and T must be related to reservoir elevation normalized to the full pool elevation. This can be done with a mixture of empirical and mechanistic considerations. First the normalized pool elevation in drawdown is defined

$$z = Z/Z_0 \qquad (2)$$

where Z is the depth at drawdown, the full pool depth is Z_0 and z is the normalized depth with $0 < z < 1$.

<u>fish travel time</u>

Fish travel time over a reach of distance X is defined

$$T = X/V \qquad (3)$$

where V is the fish velocity.

From Zabel, et al. (1998) we can approximate fish velocity as a liner function of water velocity V_w as

$$V = k\, V_w \qquad (4)$$

where $k < 0.7$ for spring chinook. The water velocity can be expressed in terms of fish depth using the velocity studies from Lower Granite Reservoir Drawdown Study (Wik et al 1993). Using information from Snake River mile 137, which is at the head of the LGR pool and is an approximation to the conditions under dam breaching, the water velocity can be expressed as a function of the normalized river depth as

$$V_w = V_{w0}\, z^{-p} \qquad (5)$$

where p = 1.4 std.errr = 0.19 with N = 3 and R-squared = 0.98 and a p-value of 0.088.

The fish velocity becomes

$$V = V_0 z^{-p} \tag{6}$$

and the travel time in terms of the full pool travel time is

$$T = z^{p} T_0 \tag{7}$$

predator density

To explore the effects of reservoir drawdown on predator density first note the total number of predators N in a segment of distance X_0 and average width Y and depth Z is

$$P = N/ YX_0 Z \tag{8}$$

Noting that to a first order the width can be expressed in terms of the normalized depth as and the full pool average width Y_0 as

$$Y = Y_0 z \tag{9}$$

then the density as a function of full pool density and normalized depth is

$$P = P_0 z^{-2} \tag{10}$$

If the predator distribution is not randomly distributed the relationship with normalized depth could be other than a square function. To generalize the result define the density as

$$P = P_0 z^{-m} \tag{12}$$

where $0 < m < 2$. If $m = 0$ the predator habitat is confined to a narrow habitat that does not change size with drawdown. If $m = 2$ the predators are randomly distributed in the reservoir. If $m = 1$ the predators are distributed in a layer that decreases area as the reservoir depth decreases.

predator reactive area

The final considerations is the impact of drawdown on the reactive area of the predator α. Since predators are visual the area depends on ability of the predators to see the smolts, which depends on some critical light level at some critical distance. Note that the ability of a predator to attack a prey depends on the ability to distinguish the prey from the background. This depends on the reflective light form the prey relative to the background which is a function of distance between predator and prey. The relationship can be expressed in terms of extinction of light by the equation

$$I_{critical} = I_0 \exp(-\sigma k C) \qquad (13)$$

where $I_{critical}$ and I_0 are the critical reflective light of the prey and background illumination, k is an extinction coefficient of light as a function of suspended sediment and C is the suspended sediment concentration in the water and can be expressed in NTUs. To develop this relationship we do not need to know the light levels or the extinction coefficient. We only need to realize that for a critical distance these factors are constant and the critical distance then is inversely proportional to the sediment concentration C. We then need to define how C changes with reservoir depth.

Several approaches are available to relate turbidity to drawdown. The HEC6 sediment transport model describes sediment suspended concentration in relation to river depth. In addition the Lower Granite drawdown study in 1992 provides information on how NTS changed with elevation. Using the information from Snake River mile 137 the sediment concentration can be related to the normalized depth with drawdown as

$$C = g' z^{-n} \qquad (14)$$

Using the maximum turbidity level corresponding with the drawdown conditions, from the regression of log (NTU) = log(g') - n log(z) we obtain g = 10, n = 1.0 std.err = 0.03 with Multiple R-Square = 0.9989, N = 3, p-value = 0.021. As the sediment was transported downstream the NTU levels decrease. Using values later in the season gave n = 0.63 std.err = 0.18 and p.value of 0.18. Now with the relationship between drawdown and predation reactive area can be expressed as

$$\alpha = g z^{-2n} \qquad (15)$$

where g is a constant depending on the behavior of the fish, water clarity and the sediment transport properties.

Survival equation

The survival equation can be expressed in terms of the drawdown depth using eq(7), (12) and (15) in eq(1) to give

$$S = \exp(-g\, P_0\, z^{2n-m} (X_0^{\,2} + (w\, z^p\, T_0)^2)^{1/2}) \qquad (16)$$

This can be simplified according to the behavior of the fish. When fish have a directed migration the average migration velocity is greater than the random velocity so $V >> w$ and $X^2 >> w^2 T^2$ and survival equation becomes a function of migration distance and

$$S = \exp(-c_1\, z^{2n-m}) \qquad (17)$$

where

$$c_1 = g\, X_0\, P_0 \qquad (18)$$

If the fish migration is slow relative to the water velocity then the migration is diffusive so $V << w$ then $X^2 << w^2 T^2$ and the survival equation is a function of travel time giving

$$S = \exp(-c_2\, z^{2n-m+p}) \qquad (19)$$

and the equation becomes

$$c_2 = g\, w\, T_0\, P_0 \qquad (20)$$

To illustrate the change in survival with changes in reservoir depth consider the ratio of survival relative to the full pool survival, S0,

$$S/S0 = \exp(c_i\,(1 - z\, qi)) \qquad (21)$$

where i = 1 for directed migration and i = 2 for diffusive migration. The ci are defined as above.

Note that at full pool z = 1 so for directed or diffusive migration the coefficient is

$$c_i = -\log S_0 \qquad (22)$$

The exponent term for directed migration is

$$q1 = 2n - m \qquad (23)$$

and for the diffusive migration it is

$$q2 = 2n - m + p \qquad (24)$$

Since $z < 1$ with drawdown the survival increases or decreases depending on the sign of qi. If $qi < 0$ then survival decreases with drawdown and if $qi > 0$ then it increases with drawdown.

Now the impact of drawdown depends on the exponent qi. To explore this further note the definitions of these terms m and n:

> m is a predator redistribution coefficient with changed in reservoir depth with drawdown where $0 < m < 2$. If $m = 0$ the predator habitat is confined to a habitat unaffected by reservoir size. If $m = 2$ the predators are randomly distributed in the reservoir and if $m = 1$ the predators are distributed in a layer such as near the surface.

> n is a predator reactive distance coefficient relating how water depth and velocity affect turbidity which in turn affects predator reactive distance. From the Lower Granite tests a first order estimate gives $n = 1$. Over time it is expected that the suspended sediment load would decrease and n would approach zero.

> p is the relationship between the normalized reservoir depth and the characteristic water velocity. From the Lower Granite Reservoir drawdown study $p = 1.4$.

If the predators are distributed randomly over the water column then $m = 2$ and the change in reservoir survival can qualitatively be identified by the value of qi.

> For directed migration at the initial drawdown $n = 1$, $m = 2$ and $q1 = 0$ so the predation rate remains unchanged. As sediments wash out of the system water clarity increases. This is represented by the n value extracted from the later summer turbidity readings giving $n = 0.6$ and $q1 = -0.8$ so the predation rate would decline over the full pool level.

> For diffusive migration, $n = 1$, $m = 2$ and $p = 1.4$ so $q2 = 1.4$ and drawdown improves survival initially. As the water clarifies as represented by $n = 0.6$ then $q2 = 0.6$ and drawdown has a smaller improvement on survival than with the initial drawdown.

If the predators are distributed heterogeneously in the habitat then the effective density change with drawdown implies $m < 2$. Under this case the drawdown is more likely to improve survival over full pool conditions.

The change in survival with drawdown can be estimated from the reservoir survival from the head of Lower Granite Pool to the confluence of the Columbia and the Snake rivers harbor dam using the full pool estimate. From CRiSP S0 = 0.82 for 1998 then ci = 0.2. The survivals under the different assumptions are as follows in Table 1 and 2. Note that the range of survival is 0.59 to 0.99. The initial PATH runs used a range of 0.85 to 0.97. The average of all the analysis is 0.85 which was taken as the low end for the A3 analysis in PATH. The low survival with directed migration with a random predator distribution is 0.59. This value should be used as the Snake River survival under drawdown and the 0.85 should be used as the average survival value with drawdown.

Table 1: Snake River survival and qi under initial drawdown n = 1.

drawdown	initial n = 1		after initial n = 0.6	
predator distribution	random m = 2	layered m = 1	random m = 2	layered m = 1
directed migration	qi = 0 S = 0.82	qi = 1 S = 0.94	qi = -0.8 S = 0.59	qi = 0.2 S = 0.85
diffusive migration	qi =1.4 S = 0.96	qi = 2.4 S = 0.99	qi =0.6 S = 0.90	qi = 1.6 S = 0.97

Conclusion

For directed migration, characteristic of spring and summer chinook, the predicted survival through the Snake River system with drawdown is between 0.59 and 0.94 depending of stage of drawdown and the distribution of predators. For a comparison the CRiSP predicted survival over the full pool reach for 1998 is 0.7 and from the confluence to Bonneville tailrace the predicted survival is 0.7. The resulting range of survival over the entire river system is then 0.41 to 0.66. This represents a range ratios of survival of drawdown relative to full pool of 0.83 to 1.6.

References

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